Clinical vascular screening of the foot: For life *and* limb

Sylvia McAra, Robert Trevethan, Lexin Wang, Paul Tinley

Peripheral arterial disease (PAD) is asymptomatic in 50–75% of cases and tends to be underdiagnosed due to the inherent difficulties in screening. Accurate peripheral vascular testing is particularly important for those at highest risk of PAD, including older people and people with diabetes, renal disease or a history of smoking. Unfortunately, commonly used tests for PAD have limited sensitivity in these most at-risk populations. This article provides guidance to support early detection of PAD using evidence-based clinical tests. It also contains a flowchart as a clinical guide and a set of recommendations concerning the measurement of toe pressures. More targeted screening can reduce morbidity and mortality rates in people with PAD who are at high risk of cardiovascular events and who often remain undiagnosed.

RACGP QI&CPD Accredited Activity CATEGORY 2

Citation: McAra S, Trevethan R, Wang L, Tinley P (2017) Clinical vascular screening of the foot: For life *and* limb. *Diabetes & Primary Care Australia* **2:** 16–24

Article points

1. This article presents evidence to inform clinical pedal vascular assessment with an update of concepts and practices.
2. Peripheral arterial disease (PAD) is prevalent but underrecognised due to difficulties with effective clinical screening, particularly in at-risk groups.
3. Enhanced awareness of PAD and the implementation of the most sensitive tests address barriers to clinical PAD screening.
4. Peripheral vascular status is important as a marker of cardiovascular risk and predictor of mortality.
5. Opportunities for preventing cardiovascular mortality exist by identifying asymptomatic PAD.

Key words

- Ankle and toe pressures
- Cardiovascular risk
- Doppler ultrasound
- Peripheral arterial disease
- Vascular assessment

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See page 23 for author details.

Peripheral arterial disease (PAD) is a degenerative condition involving changes of the arterial walls and endothelial responses. Large epidemiological studies confirm the importance of PAD as an indicator for generalised atherosclerosis (Caro et al, 2005; Diehm et al, 2009). Low peripheral perfusion indicates the presence of widespread atheromatous disease (Greenland et al, 2001). Distal perfusion predicts the risk of pedal wounds and their healing potential (Sonter et al, 2014), but, of greater significance, strong links exist between PAD and cardiovascular disease (CVD; Hooi et al, 2004; Caro et al, 2005). Advanced age, male gender, diabetes, renal disease and smoking are also associated with a higher prevalence and severity of PAD (Caro et al, 2005). The presence of PAD carries the same mortality risk as a previous myocardial infarction or stroke (Caro et al, 2005).

Historically, symptoms and visual signs have been used as indicators to generate the index of suspicion for further clinical testing. However, this approach is flawed because PAD is asymptomatic in 50–75% of cases (Diehm et al, 2009) and most visual signs of vascular insufficiency are low in sensitivity for PAD screening (McGee and Boyko, 1998; Williams et al, 2005). The ankle–brachial index (ABI) has value in screening general populations, but loses sensitivity in proportion to an increasing degree of vessel stenosis, a primary pathophysiological manifestation of PAD (Xu et al, 2010). Absolute toe pressures and toe–brachial indices (TBIs) are now being recommended and are attracting research attention as adjuncts to improve the quality of PAD screening.

Why screen for PAD?

PAD is prevalent and often invisible, and it is underdiagnosed and commonly undertreated (Lange et al, 2004) due to barriers to screening (Haigh et al, 2013) and difficulties of recognition (Hirsch et al, 2001; Menz, 2010). A high proportion of cases of sudden cardiac death (25%) have no previously identified symptoms or appreciable risk factors of CVD (Greenland et al, 2001). There is, therefore, a need for tests and markers to assist clinicians in identifying people at risk (Aboyans and Criqui,

2006; Aboyans et al, 2008; World Health Organization, 2013; Brownrigg et al, 2016), particularly when risks can be modified with interventions (Hinchcliffe et al, 2015).

Prevalence, identification and classification of PAD

Estimates of the prevalence of PAD vary widely from 4–57%, depending on how the disease is identified and on age and risk factor distributions in specific populations (Caro et al, 2005). In a summary statement about prevalence, Høyer et al (2013) cite evidence that more than 50% of people with PAD are asymptomatic.

PAD is best known for ischaemic pain associated with intermittent claudication. However, in a large study, only 11% of people with PAD had intermittent claudication (Hirsch et al, 2001). The prevalence of pathology is similar in symptomatic and asymptomatic PAD (Diehm et al, 2009), but significant impairment of the vascular tree often exists before and without any symptoms or signs. Previously, the severity of PAD has been described and stratified using the symptoms of claudication and rest pain, then tissue death, as in the Rutherford and Fontaine classification systems (Mills et al, 2014). Due to a growing appreciation of both the prevalence and pathological significance of asymptomatic PAD, new international guidelines for vascular surgery contain recommendations that pedal risk stratification be based, instead of on symptoms, on an algorithm including foot wound status, ischaemia and infection (Mills et al, 2014).

Standard CVD risk scores, such as the Framingham risk score, have low-, middle- and high-risk stratification categories. The diagnostic utility of these indicators may be improved by adding non-invasive clinical pedal vascular assessment to identify asymptomatic PAD in the intermediate risk group (Greenland et al, 2001).

Limitations in screening for PAD

A major limitation associated with screening for PAD is that there is currently no agreement concerning the use of any single test or combination of tests to detect PAD in primary healthcare settings. People's medical history, as well as their pulses, pedal Doppler waveforms, ABIs and TBIs, are quoted in guidelines as being strongly recommended, but there is little evidence to support their use (Hinchcliffe et al, 2015). Most clinical tests used for PAD screening have low sensitivity and therefore fail to identify a large proportion of people who have the disease (Williams et al, 2005; Brownrigg et al, 2016). Many people with PAD have no obvious visual signs, and visual signs such as skin colour, lack of hair growth, nail changes and skin atrophy are low in sensitivity for PAD detection (Williams et al, 2005; Menz, 2010). In addition to visual screening, standard clinical tests include assessment of pulses, impressions of skin temperature, capillary refilling time and possibly ABIs. These screening processes may underestimate PAD by up to 60% (Williams et al, 2005; Høyer et al, 2013). Pulse palpation, although a useful clinical skill, is not adequate as a primary screening tool for PAD due to its variable sensitivity, which declines as vascular disease states advance (McGee and Boyko, 1998; Williams et al, 2005).

The ABI has been the cornerstone of peripheral vascular assessment in primary care for PAD and associated CVD risk, and it is supported by four decades of evidence (Caruana et al, 2005; Rooke et al, 2011). However, when Australian GPs were surveyed for the barriers they experienced in performing vascular assessment, 58% indicated that they did not use ABIs to perform vascular assessments, with time constraints stated as the greatest barrier, followed by lack of equipment and skills (Haigh et al, 2013). This is despite Medicare rebates currently applying for both toe- and ankle-pressure studies (See *Table 1*).

The ABI is useful for identifying CVD risk in the general population (Caruana et al, 2005; Guo et al, 2008). However, its sensitivity is reduced in proportion to the degree of atherosclerosis and vascular stenosis, both of which are common in people of advanced age and those who have complications of diabetes, especially neuropathy (Aboyans et al, 2008; Xu et al, 2010; Craike et al, 2013; Formosa et al,

Page points

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2. A major limitation associated with screening for PAD is that there is currently no agreement concerning the use of any single test or combination of tests to detect PAD in primary healthcare settings.

Table 1. Medicare fees and benefits for vascular testing (Australian Government Department of Health, 2016).

Test	Item number	Fees and Medicare benefits
Ankle– or toe–brachial index and arterial waveform study **Measurement of ankle:brachial indices and arterial waveform analysis** Measurement of posterior tibial and dorsalis pedis (or toe) and brachial arterial pressures bilaterally using Doppler or plethysmographic techniques, the calculation of ankle (or toe)–brachial systolic pressure indices and assessment of arterial waveforms for the evaluation of lower extremity arterial disease, examination, hard copy trace and report.	11610	*Fee*: $63.75 *Benefit*: 75% = $47.85 85% = $54.20
Ankle– or toe–brachial index-exercise study **Exercise study for the evaluation of lower extremity arterial disease** Measurement of posterior tibial and dorsalis pedis (or toe) and brachial arterial pressures bilaterally using Doppler or plethysmographic techniques, the calculation of ankle (or toe) brachial systolic pressure indices for the evaluation of lower extremity arterial disease at rest and following exercise using a treadmill or bicycle ergometer or other such equipment where the exercise workload is quantifiably documented, examination and report.	11612	*Fee*: $112.40 *Benefit*: 75% = $84.30 85% = $95.55

2013; Hyun et al, 2014).

Medial arterial calcification is prevalent in renal disease (An et al, 2010) and in long-term type 1 diabetes (Ix et al, 2012). It places limitations on the sensitivity of vascular pressure measurements due to the associated non-compressibility of vessels.

Sensitive clinical screening methods

Buerger's sign demonstrates the pathophysiology of endothelial-driven maximal vasodilation of vessels in the presence of tissue ischaemia, resulting in pallor on elevation from rapid and extensive draining, and rubor on dependency with gravity-assisted refill of dilated vessels (*Figure 1*). Buerger's sign has high sensitivity, up to 100% in severe arterial disease (McGee and Boyko, 1998). It, therefore, holds an important place in the PAD screening armoury.

A degree of sensitive clinical screening can also be achieved by assessing pedal arteries by means of handheld Doppler ultrasound

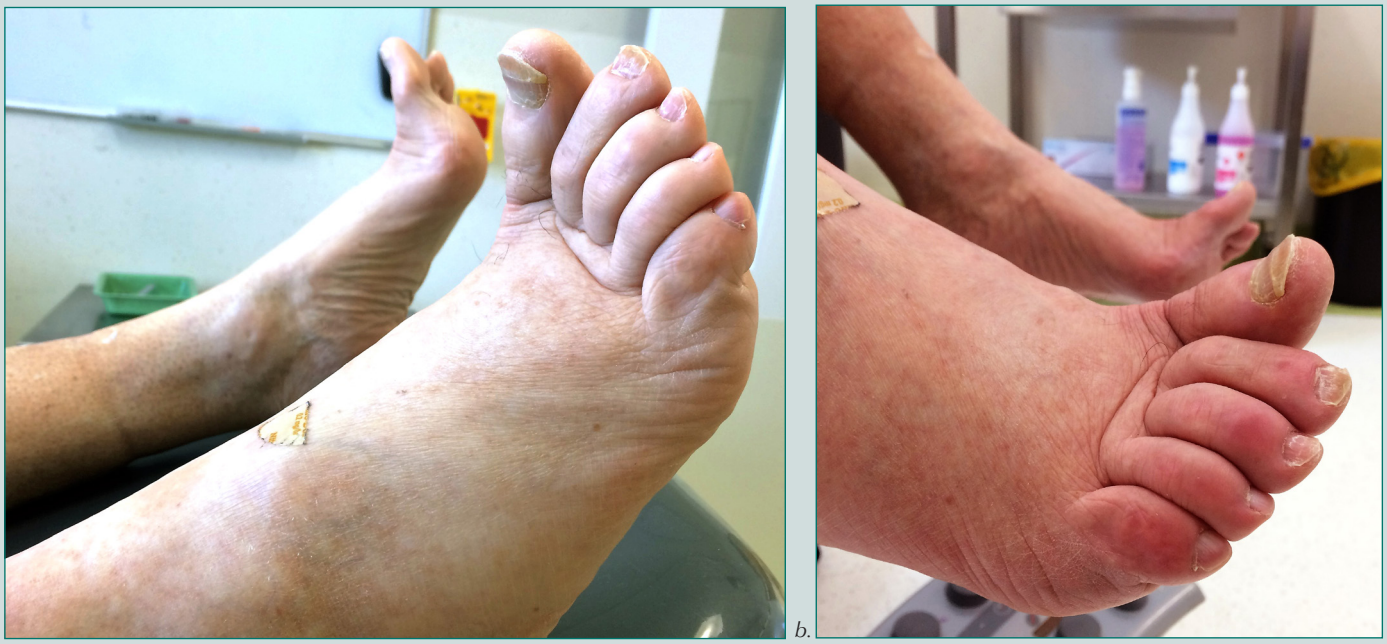


Figure 1. Buerger's sign: pallor in elevation (a), rubor in dependency (b). Colour change is notable within 10 seconds of position change. Buerger's sign is the only visual sign that is highly sensitive for peripheral arterial disease screening. See also http://bit.ly/2gUqGzS (Kang and Chung, 2007 [accessed 05.12.16]).

and waveform analysis ([*Figure 2*] as distinct from laboratory Doppler ultrasound colour imaging). Sound and waveform analysis is a good indicator of pathology and has prognostic relevance, and it also maintains sensitivity in the presence of neuropathy (Williams et al, 2005; Alavi et al, 2015). Although some ambiguity is associated with biphasic and triphasic Doppler signals (both can be confounded by a variety of influences including flow turbulence and valvular incompetence), monophasic Doppler signals are highly sensitive indicators of significant vascular pathology. Doppler analysis can be performed in the same brief time period needed for other auscultation techniques. Investigations of the sensitivity of the ABI versus Doppler ultrasound and waveforms in PAD screening endorse Doppler and document the limitations of the reliability of the ABI alone (Formosa et al, 2013; Alavi et al, 2015).

Additional prospects for effective screening are offered by TBIs. In a recent systematic review based on seven studies, Tehan et al (2016) found that the sensitivity of TBIs for detecting PAD ranged from 45% to 100%, with TBIs being most sensitive in samples known to be at risk of PAD and among people who experienced intermittent claudication. The small number of studies reviewed were of varying quality and comprised disparate samples, indicating the need for more extensive, systematic and rigorous investigation regarding the effectiveness of TBIs for detecting PAD.

Nevertheless, use of the TBI in place of the ABI is recommended because of the TBI's superior sensitivity among people who have known vascular disease risk – specifically people with diabetes and renal disease and of advanced age (Williams et al, 2005; Aboyans et al, 2008; Hyun et al, 2014). An alternative assessment algorithm incorporating Doppler ultrasound waveform analysis and TBIs for people with diabetes has been found to increase the sensitivity for PAD detection from 33% to 50% (Craike and Chuter, 2015).

When vascular disease is widespread and other comorbidities (such as cardiac output disorders, respiratory disease and diabetes) complicate systemic pressure measurements, absolute toe pressures are probably more valuable than are indices such as ABIs and TBIs (Caruana et al, 2005; Potier et al, 2011; Okada et al, 2015; McAra and Trevethan, 2016).

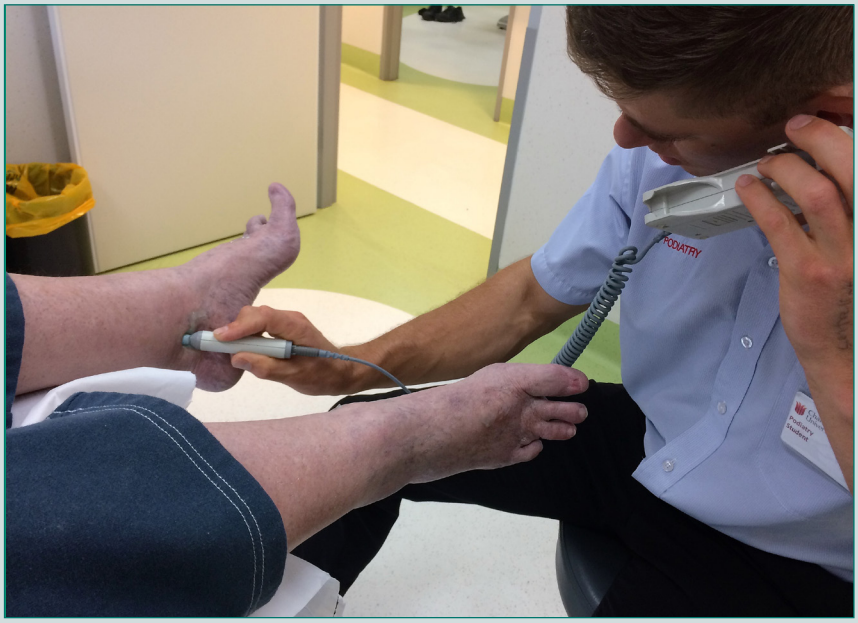


Figure 2. The presence of a monophasic signal in a pedal artery from handheld Doppler ultrasound is a highly sensitive indicator of peripheral arterial disease. Tibialis posterior, dorsalis pedis and tibialis anterior arteries are useful for auscultation and the test can be performed in less than a minute.

The use of X-ray should be considered as a novel and important part of PAD screening because both toe and ankle vessels may become calcified, and, as a result, pressure measurement can be spuriously inflated due to vessel non-compressibility. By identifying the presence of calcification, X-rays provide a more informed context within which to interpret toe and ankle pressures. In a study of people with type 1 diabetes, the incidence of medial arterial calcification was 57% on plain X-ray, but only 8% of these people had ABIs >1.30 (Ix et al, 2012), demonstrating not only the value of X-ray, but also, as the researchers concluded, that the ABI should not to be relied on for identifying PAD due to its underdiagnosis of the disease.

More research is needed about the prevalence of toe calcification to sharpen understanding of the utility of toe pressures in groups at highest risk of PAD. However, it is already known that

toes are affected by calcification later than are ankles and only in cases of the most severe and long-standing disease.

There is consensus that larger-scale studies are needed to consolidate normal and pathological TBI ranges and recommendations for TBI and toe pressure test procedures (Høyer et al, 2013; Sonter et al, 2014; McAra and Trevethan, 2016; Tehan et al, 2016). However, there is evidence that the most sensitive screening procedures parallel the most accurate prognostic indicators. Toe pressures and TBIs have been linked to amputation prognosis by a systematic review of the literature, which indicated that there is a 3.25 times greater risk of non-healing when toe pressures are <30 mmHg (Sonter et al, 2014). In a study of people with diabetes comparing healing outcomes with vascular assessments from minor pedal amputations, significant relationships were found for TBIs, absolute toe pressures and Doppler waveforms. The ABI did not have a significant relationship with healing outcomes (Caruana et al, 2005) and therefore should not be relied upon to screen for PAD. The flowchart in *Figure 3* represents a synthesis of the current evidence-based literature and provides a suggested clinical pathway for pedal vascular assessment.

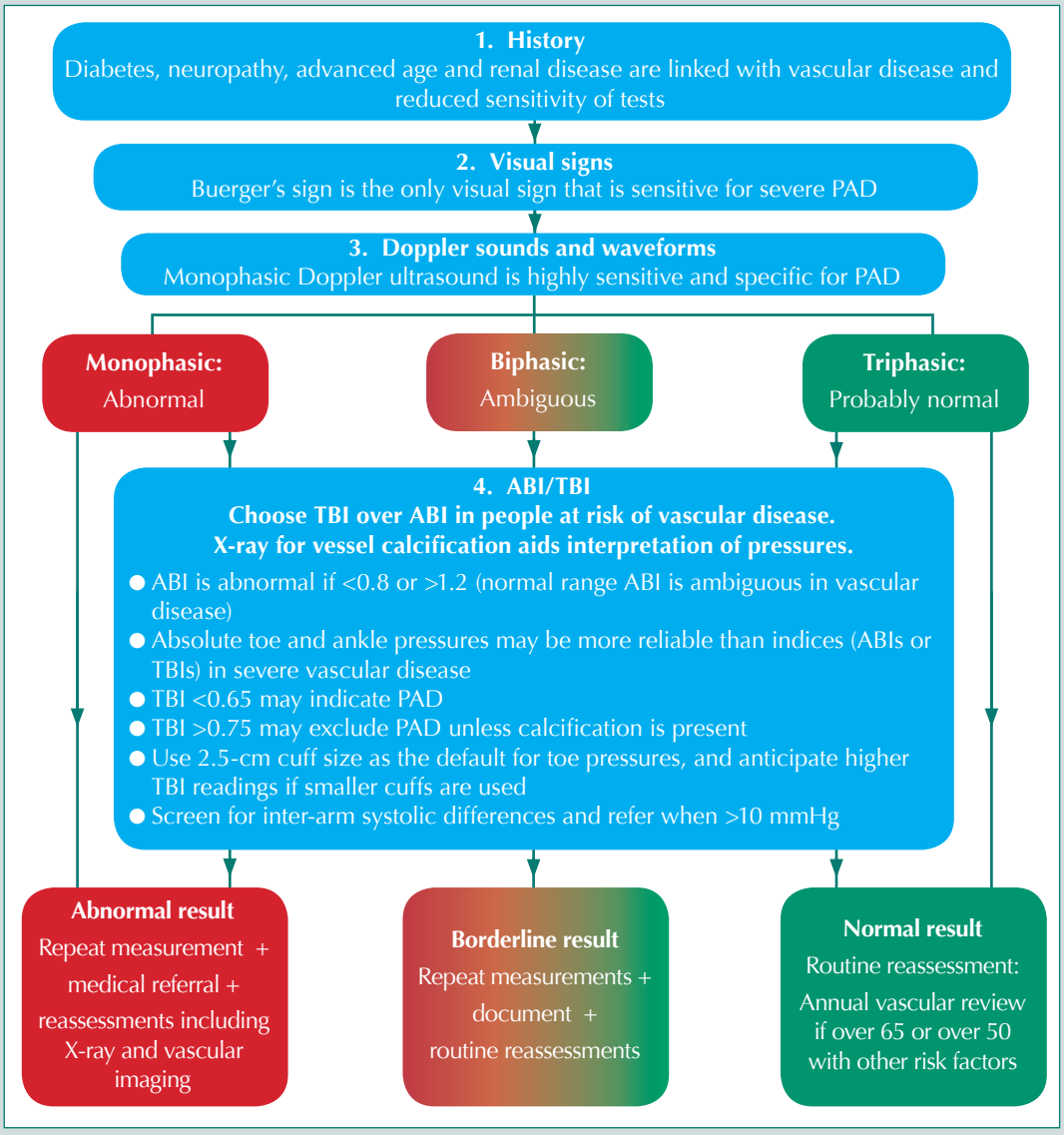


Figure 3. Pedal vascular assessment guide. ABI=ankle–brachial index; PAD=Peripheral arterial disease; TBI=toe–brachial index.

Measurement of vascular pressures

Brachial pressures: Why check for inter-arm differences?

Brachial blood pressures should ideally be taken in both arms, particularly in people at risk of PAD, as inter-arm differences in brachial blood pressure can predict mortality. In a recent meta-analysis (Clark et al, 2012), inter-arm differences >10 mmHg were shown to be a marker of cardiovascular mortality. Beyond an initial 10 mmHg inter-arm difference, every additional 1 mmHg difference accounted for a 5% greater hazard ratio when the CVD risk score was >20%. Obtaining brachial blood pressures provides an opportunity for health professionals involved in vascular screening to identify and assess people for appropriate medical management, including investigation and targeting of CVD risk factors.

Lower limb pressure measurement considerations

Lower limb vascular pressure measurements are known to be variable and subject to influence by numerous factors, including ambient and skin temperatures, length of any rest period before measurement, respiratory and cardiac outputs, the comfort of the person being tested, medications and cuff sizes (Påhlsson et al, 2004; Welch Allyn Inc, 2010; Sadler et al, 2014; Sonter et al, 2014; McAra and Trevethan, 2016). Some recommendations regarding measurement of blood pressure in toes are summarised in *Box 1*.

One of the most important test conditions, and most pertinent to lower limb testing, is the relative position of the test segment. Lying with heart and foot at the same level is the ideal measurement position (*Figure 4*). Any elevation of the limb relative to the heart markedly decreases pressures (Welch Allyn Inc, 2010) and the reduction is in proportion to vascular impairment (Wiger and Styf, 1998). This physiological principle, which is magnified in PAD and evident in Buerger's sign, has an immediate influence on pressure

"Lower limb vascular pressure measurements are known to be variable and subject to influence by numerous factors."

Box 1. Recommendations for toe pressure measurement.

- Assess toe pressures in an ambient temperature between 21 and 24°C (Bonham, 2011).
- Be aware that elevated blood pressure readings are likely if people being tested have a full bladder or have eaten, consumed caffeinated or alcoholic beverages, smoked, or engaged in vigorous physical activity within an hour of testing (Pickering et al, 2005).
- Place the person in a supine position with the heart, arms and feet at the same level (Bonham, 2011). Consider elevating the head only with one or two pillows for comfort. If taking a brachial pressure, place the arm on a pillow to bring it up to the same level as the heart (Pickering et al, 2005).
- Provide an initial 10 minutes' rest period of sitting or lying (Sadler et al, 2014), preferably lying.
- Ensure skin temperature is at least 19°C (Cloete et al, 2009). Use some form of warming if necessary.
- Avoid perturbations such as the subject's talking, moving, coughing or sneezing (McAra and Trevethan, 2016).
- Use photoplethysmography (PPG) as the sensing method, preferably using an automated device (Pérez Martin et al, 2010).
- Use an occlusion cuff of 2.5 cm if possible; if smaller cuffs are used, allow for the possibility of inflated readings (Påhlsson et al, 2004).
- If measuring toe–brachial indices (TBIs), for each limb, take two readings of brachial systolic pressures and toe systolic pressures and, for each limb, average the readings if they are similar to each other. However, if they differ noticeably, take three or more readings and make a judicious decision about which ones should be averaged. Obtain brachial and pedal readings as simultaneously as possible (McAra and Trevethan, 2016).
- Raise a high index of suspicion of peripheral arterial disease with a TBI reading of <0.65 on either foot (Høyer et al, 2013) if a 2.5-cm cuff is used, or with a higher TBI reading if a smaller cuff is used.
- Examine plain X-ray for the presence of any digital calcification to assist in the interpretation of toe pressure values.

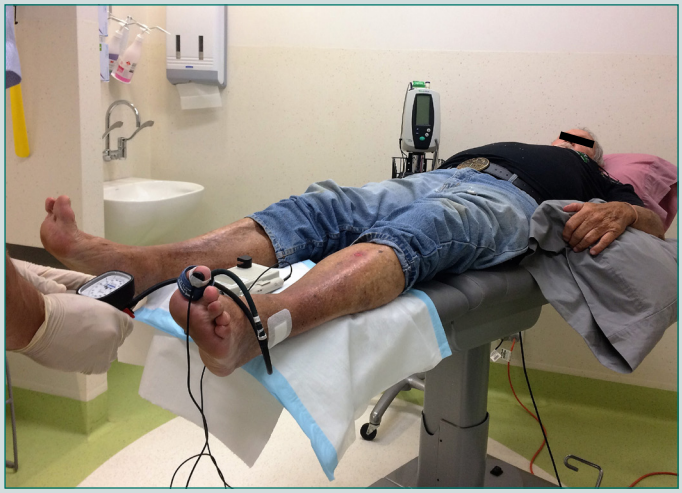
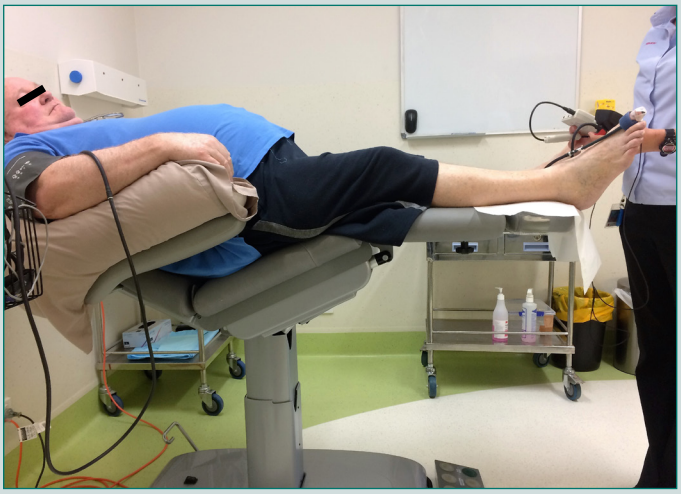
a.  b. 

Figure 4. Positioning for vascular pressure measurement requires the heart and the sites to be measured on the same horizontal plane. Flat lying is ideal (a). Note the pillows for the head and the brachium (Pickering et al, 2005). The angled chair allows for correct alignment when flat lying is not practical due to the person's conditions (b).

"Attention to test conditions and awareness of pathophysiology associated with peripheral arterial disease can lead to more effective screening."

readings as formalised with the pole test (Menz, 2010). As well as segment positioning being an important principle affecting accurate measurement, it extends to management: positioning of the foot in relative dependency may boost supply and thereby assist in arterial wound healing and the relief of rest pain.

The issue of cuff size for toe pressures is important and has been underappreciated in the literature to date. Smaller cuff sizes have been demonstrated to produce higher blood pressure values (Påhlsson et al, 2004), and this can present problems, particularly as automated twin-cuff devices frequently require the use of a smaller occlusion cuff to fit the toe (McAra and Trevethan, 2016). As a result of commonly found fluctuations in vascular pressures, particularly brachial pressures in diabetes, repeat and serial testing of pedal pressures and indices is recommended (Sonter et al, 2014; McAra and Trevethan 2016).

Conclusions

- Effective PAD identification in primary clinical contact settings can improve disease identification and monitoring, and, importantly, CVD-risk modification.
- Reliance on tests with low sensitivity has pervaded understanding and practice in the identification of PAD. This has contributed to a substantial proportion of missed diagnoses.
- The ABI has fulfilled a valuable role in screening for PAD and CVD in the general population. However, ABI sensitivity declines substantially in populations at the highest risk of PAD and CVD when vessel stenosis becomes prevalent.
- The most sensitive clinical options for PAD screening in at-risk populations are Buerger's sign, Doppler ultrasound waveforms and, more recently, toe pressures (including TBIs). X-rays can assist in identifying vessel calcification, thus providing important information for interpreting vascular pressure values.
- Time saved by avoiding less sensitive clinical assessments could be used to conduct more sensitive screening procedures.
- Attention to test conditions and awareness of pathophysiology associated with PAD can lead to more effective screening. ■

Competing interests

No competing interests to declare.

Acknowledgements

Richard Barkas, Martin Forbes, Rajna Ogrin, Barry Pitman and Caroline Robinson provided helpful suggestions, comments and advice concerning earlier drafts of this manuscript.

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Participants should read the preceding article before answering the multiple choice questions below. There is ONE correct answer to each question. After submitting your answers online, you will be immediately notified of your score. A pass mark of 70% is required to obtain a certificate of successful participation; however, it is possible to take the test a maximum of three times. A short explanation of the correct answer is provided. Before accessing your certificate, you will be given the opportunity to evaluate the activity and reflect on the module, stating how you will use what you have learnt in practice. The CPD centre keeps a record of your CPD activities and provides the option to add items to an action plan, which will help you to collate evidence for your annual appraisal.

1. In what percentage of sudden cardiac deaths are there no previously determined cardiovascular risk factors? **Select ONE option only.**

   A. 1%
   B. 10%
   C. 25%
   D. 50%

2. The risk of mortality with peripheral arterial disease (PAD) is similar to the risk of mortality in which of the following groups of people? **Select ONE option only.**

   A. People who smoke cigarettes
   B. People who have diabetes
   C. People with a history of a previous cardiovascular or cerebrovascular event
   D. People with renal disease

3. According to Caro et al (2005), what is the estimated range of prevalence of PAD? **Select ONE option only.**

   A. <1%
   B. 4–57%
   C. 15–25%
   D. 10–20%

4. According to Høyer et al (2013), what percentage of people with PAD are asymptomatic? **Select ONE option only.**

   A. <20%
   B. <40%
   C. >50%
   D. >80%

5. Of the visual signs of PAD, which of the following has the highest sensitivity? **Select ONE option only.**

   A. Colour
   B. Pallor
   C. Skin atrophy
   D. Buerger's sign

6. The ankle–brachial index (ABI) is useful for identifying cardiovascular disease risk in the general population; however, it has reduced sensitivity in proportion to the degree of vascular stenosis present in an individual. Which of the following factors reduces the sensitivity of the ABI for PAD screening? **Select ONE option only.**

   A. Diabetes
   B. Neuropathy
   C. Renal disease
   D. Advanced age
   E. All of the above

7. In a study by Craike and Chuter (2015), using an assessment algorithm incorporating Doppler ultrasound waveform analysis and TBIs (toe–brachial indices) for people with diabetes increased sensitivity for PAD detection to how much? **Select ONE option only.**

   A. 11%
   B. 26%
   C. 50%
   D. 72%
   E. 80%

8. In a recent meta-analysis of inter-arm differences in brachial systolic blood pressures (Clarke et al, 2012), what was the threshold shown to be a marker of cardiovascular mortality in the presence of a CVD risk score of >20%? **Select ONE option only.**

   A. A 45 mmHg difference
   B. A 25 mmHg difference
   C. A 10 mmHg difference
   D. A 5 mmHg difference

9. Using a handheld Doppler ultrasound, the result of a monophasic signal (sound or waveform) is indicative of the following diagnosis? **Select ONE option only.**
   A. A normal result
   B. PAD is highly likely
   C. An ambiguous outcome with regard to PAD
   D. PAD is very unlikely

10. Which of the following is the most important test element in obtaining accurate vascular pressures of the lower limb? **Select ONE option only.**

    A. Eliminating differences in elevation between the heart and the measured segment
    B. Environmental temperatures
    C. Comfort of the patient
    D. Considerations of peripheral vasodilatory medications